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Original Research Paper

Investigation of Geotechnical Engineering Properties of Subsurface Soils in Bonny Island, Eastern Niger Delta

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ABSTRACT

The purpose of the investigation was to evaluate the subsurface lithologies as well as to examine the properties of the soils in the area, especially with respect to their strengths and bearing capacities, with a view to determining the suitability or otherwise of the subsoil as bearing media for a shallow foundation system. Borings for subsurface exploration in the area were made at three (3) well spaced locations with a hand auger to a maximum depth of 30m each below the existing ground level and the execution of two (2) Cone Penetrometer Tests (CPTs) to maximum depth or refusal. The study is aimed at determining the suitability of the location prior to the design and construction of foundations in the area. Results of the study reveal that BH 1 is characterized by soft, dark grey peat with a thickness of 2.0m. This layer of peat is underlain to 9.0m by medium dense, dark grey fine sand and in turn overlies medium dense to dense, grey fine to medium sand to the terminal depth at 30.0m, and becoming light grey at 24.0m. In BH 2, the topsoil is soft, dark grey peat to 0.50m. Underlying the above layer of peat to 1.0m is loose, light brown fine sand with plant roots. From 1.0m to 3.0m is a layer of soft, grey sandy silt which is underlain by medium dense, grey fine sand of 3.0m thickness. From 6.0m to 9.0m is dark grey, fine sand with intercalation of silty clay at 9.0m and from 10.0m to 22.0m is medium dense, grey fine to medium sand. From 23.0m to the terminal depth at 30.0m is medium dense to dense, brown fine to medium sand. The study shows that the topsoil in borehole 3 is similar to borehole 2. However, underlying the peat in BH 3 is brown fine sand to 1.0m and underlying the fine sand to 3.0m is medium dense, light brown fine sand. From 3.0m to 14.0m is medium to dense, light grey fine sand which in turn is underlain by medium dense to dense, fine to medium sand of 8.0m thickness. From 22.0m to the terminal depth at 30.0m is medium dense to dense, grey fine medium sand. Generally, the sand layers in all the boreholes exhibited high SPT values at deeper depths. The results obtained from this study have emphasized the usefulness of geotechnical studies in establishing variation in lithology accompanied by variation in the allowable bearing pressure of foundation soils.

INTRODUCTION

Many property developers in the Niger Delta region of Nigeria ignore drastically the role of geotechnical information in the planning, design, construction, operation as well as safety of civil engineering infrastructures. This neglect results to failure of structures. Frequent structural failure of civil engineering infrastructures in parts of the country has become a source of worry to so many persons. It is for this reason that a clear understanding of the occurrence, composition, distribution, geologic history as well as the geotechnical properties of subsurface soils in the area is necessary.

Site investigation in one form or the other is always required for long term stability of structures. The extent of such investigation depends on the importance and foundation arrangement of the structure, the complexity of the soil conditions and available information on the behaviour of existing foundations on similar soils. However, the failure of many structures mostly in locations where the subsurface soils condition were unknown prior to construction has brought the importance of subsurface soils investigations prior to construction to the fore (Adebisi & Oloruntola 2006).

Considering the fact that the Eastern Niger Delta is within the coastal zone, geotechnical investigation/considerations are very desirable. The coastal zone which comprises the beach ridges and mangrove swamps is underlain by an alternating sequence of sand and clay with a high frequency of occurrence of clay within 10m below the ground surface. Because of the nearness of these compressible clays to the surface, the influence of imposed loads results to consolidation settlement. The impact of the imposed load is exacerbated by the thickness and consistency of the compressible layer. This, in addition to other intrinsic factors contributes to the failure of civil engineering structures.

The use of cone penetration tests as an *in-situ* test during subsoil investigation for structures such as building has since gained wide popularity over the years (Adeyemi & Osammor 2001). Some of the reasons for its increasing recognition as

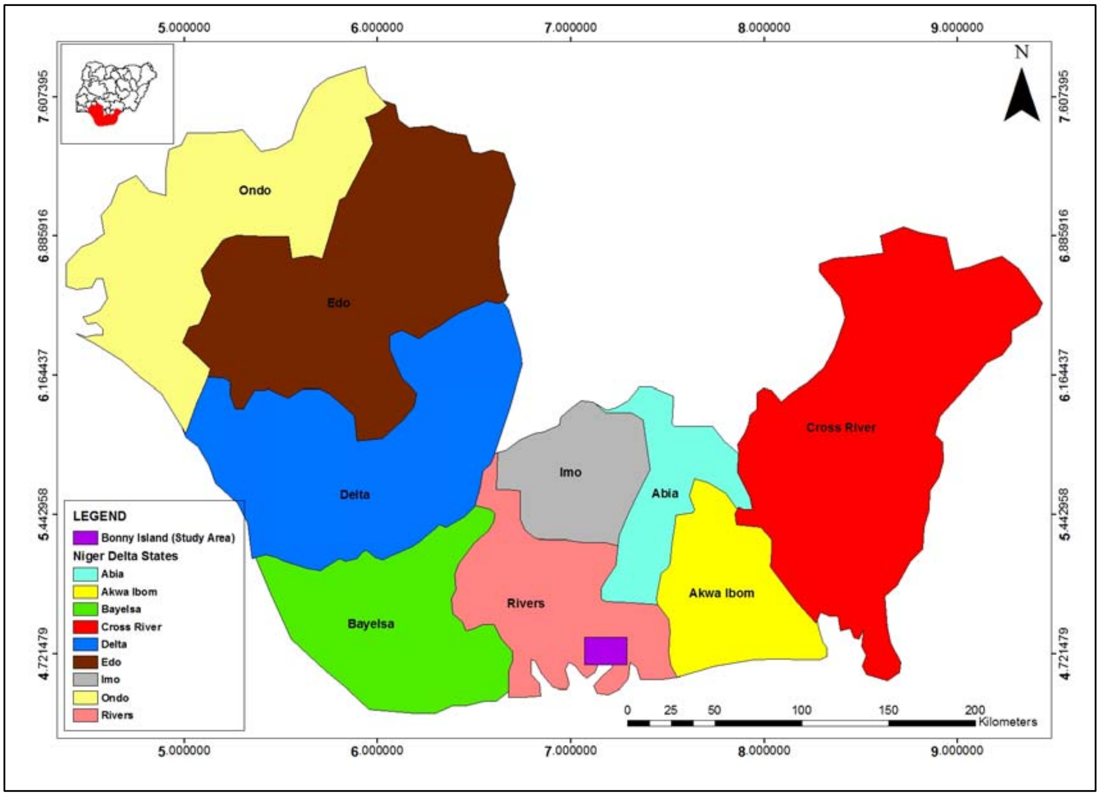

Fig. 1: Map of Bonny island showing the study area.

enumerated by Campanella et al. (1982) include easy standardization of the procedure and equipment, simple and reliable test results, measured parameters like cone resistance and sleeve friction are accurate and rapid to obtain and relatively cheap nature of the test and its ability to delineate subsurface strata (Adebisi & Oloruntola 2006).

The need, therefore, to evaluate the subsurface lithologies and examine the geotechnical engineering characteristics of the sub-soils in the area, including consistency limits, settlement characteristics, particle size distribution (PSD) and their bearing capacities with respect to shallow foundations becomes very necessary. This study therefore is aimed at evaluating the suitability of sub-soil conditions. Suggestions on soil improvements and recommendations of appropriate foundation types and design parameters in the area are made.

DESCRIPTION OF STUDY LOCATION

The study location is within the premises of the Nigerian Ports Authority (NPA), Bonny Island, Rivers State, Eastern Niger Delta, Nigeria. Accessibility to the site is by water transport. Geologically, the area of investigation falls within the oil rich Niger Delta Sedimentary Basin.

Bonny Island (Fig. 1) falls within the Beach ridges onshore geomorphic sub-environment of the Niger Delta. Geologically, these comprise Pleistocene and Recent sediments deposited by fluvial and shallow continental shelf hydrodynamic processes. The area is characterized by strong wave and tidal action, which further compacts the sediments. Plant growth on beach ridges over the years has resulted in the formation of extensive primary tropical freshwater forest. Energy conditions decrease from shore face to outer edge. The litho facies include the delta tip, mainly evenly laminated fine to medium sand.

The hydrogeology of the area is highly influenced by the presence of ferruginous sandy formation due to high oxidation condition of the near surface aquifers, and predominant saline water intrusion. The sand forms the major aquifer in the area while the clay forms the aquitards. The water table in the area varies with season. The area has a declining water table during the dry season. Generally, water table ranges between 0.1 (surface) and 3m depending on the season. Water table in the area is dynamic with reversal tidal influence. Generally, the Delta is characterized by three formations, namely Akata (oldest), Agbada and Benin (youngest). These formations consist primarily of regressive Tertiary age sediments. The detailed geology of the Niger Delta formation is given by Reyment (1965), and Short & Stauble (1967).

Table 1: Particle size statistics.

BH No	Depth (m)	Effective Particle Size D_{10} (mm)	D_{30} (mm)	Mean Particle Size D_{50} (mm)	D_{60} (mm)	Coef. of Uniformity $Cu=D_{60}/D_{10}$	Coef. of Curvature $Cc=D30^2/(D_{10}{}^*D_{60}$	Coef. of Permeability $K=C^*D_{10}{}^2$ (m/sec)
BH-1	3.00	0.091	0.240	0.330	0.360	3.956	1.758	0.00083
	8.00	0.096	0.300	0.330	0.370	3.854	2.534	0.00092
	12.00	0.170	0.380	0.490	0.540	3.176	1.573	0.00289
	17.00	0.170	0.300	0.490	0.530	3.118	0.999	0.00289
	25.00	0.180	0.380	0.490	0.530	2.944	1.514	0.00324
	30.00	0.160	0.360	0.460	0.510	3.188	1.588	0.00256
BH-2	5.00	0.110	0.280	0.330	0.360	3.273	1.980	0.00121
	7.00	0.110	0.300	0.340	0.370	3.364	2.211	0.00121
	12.00	0.210	0.400	0.500	0.550	2.619	1.385	0.00441
	18.00	0.240	0.400	0.500	0.540	2.250	1.235	0.00576
	23.00	0.250	0.400	0.500	0.530	2.120	1.208	0.00625
	30.00	0.200	0.400	0.500	0.530	2.650	1.509	0.00400
BH-3	1.00	0.150	0.300	0.340	0.370	2.467	1.622	0.00225
	3.00	0.091	0.260	0.340	0.370	4.066	2.008	0.00083
	6.00	0.130	0.290	0.350	0.390	3.000	1.659	0.00169
	14.00	0.130	0.300	0.350	0.390	3.000	1.775	0.00169
	20.00	0.220	0.360	0.450	0.500	2.273	1.178	0.00484
	24.00	0.210	0.350	0.425	0.490	2.333	1.190	0.00441
	30.00	0.170	0.330	0.400	0.470	2.765	1.363	0.00289

Table 2: The variations in the index and engineering properties of the sands in the study area.

Details	Average
D_{10} Effective Diameter (mm)	0.166
D_{30} (mm)	0.335
D_{50} Mean Particle (mm)	0.421
D_{60} (mm)	0.463
Coefficient Uniformity (Cu)	2.818
Coefficient of Curvature (Cc)	1.500
Coefficient of Permeability (K) m/sec	2.99×10^{-3}
Angle of Internal Friction	30
Unit Weight	16.93
Specific Gravity	2.64

STUDY TECHNIQUES

The investigation comprised mainly exploring three (3) geotechnical boreholes with soil sampling and measurement of water table and the execution of two (2) cone penetration tests.

Boring: The boreholes were drilled by the shell and auger cable percussive drilling method, using a hand rig. The hand rig is fitted with a free fall auger. The auger is lifted to a height of about 1.0m above the ground level, using gloved hands, and allowed to free-fall under gravity to advance the boring. As the auger falls it cuts through the soil such that the cut soil material is retained in it until it is emptied out. To prevent collapse of the borehole wall, the hole is lined with casings or shell corresponding to the size of the auger being used for the drilling. As the drilling continues, the auger drops into the open hole until the time the sample is to be taken.

Representative disturbed samples were taken at regular intervals of 1.0m depth, and also when a change in soil type was observed. The samples were used for a detailed and systematic description of the soil in each stratum in terms of its visual and haptic properties and for laboratory analysis.

Standard Penetration Tests (SPT) was carried out at regular intervals of depth in the granular sediments in order to assess their *in-situ* densities. In this test, the number of blows required to drive the standard sampling spoon 300m penetration after the initial sitting drive was recorded as the N_{SPT} value.

Two cone penetration tests were carried out to refusal. Cone Penetrometer of 25KN capacity was used in the cone resistance soundings. Continuous sounding procedure was adopted in the test. The cone is first forced into the ground to a distance of 10cm by the application of force to the outer sounding tubes. The cone is then pushed out to a distance of about 4cm by the application of force to the inner rods only and the magnitude of the force required to achieve this, is measured on the pressure gauges and recorded, and this is the cone resistance.

Laboratory tests: Detailed laboratory investigations were carried out on representative disturbed samples obtained from the boreholes for the classification tests. All tests were carried out in accordance with BS 2377 (1990) methods of tests for soil for civil engineering purposes. Particle size distribution (PSD) of the recovered cohesion-less soils was determined by sieve analysis.

Table 3: Results of CPT 1.

Depth (m)	(kg/cm^2)	Estimated Undrained Strength (KPa)	Ultimate bearing Capacity (KPa)	Allowable bearing Capacity (KPa)
0.00	0	0.00	0.00	0.00
0.20	4	13.21	78.92	26.31
0.40	3	9.76	62.83	20.94
0.60	3	9.64	65.75	21.92
0.80	3	9.52	68.66	22.89
1.00	3	9.40	71.58	23.86
1.20	2	5.95	55.50	18.50
1.40	2	5.83	58.41	19.47
1.60	2	5.71	61.33	20.44
1.80	2	5.59	64.24	21.41
2.00	30	98.80	599.16	199.72
2.20	24	78.68	488.08	162.69
2.40	30	98.56	604.99	201.66
2.60	35	115.11	702.91	234.30
2.80	35	114.99	705.82	235.27
3.00	42	138.20	841.74	280.58
3.20	48	158.08	958.66	319.55
3.40	44	144.63	885.57	295.19
3.60	44	144.51	888.49	296.16
3.80	47	154.39	948.40	316.13
4.00	52	170.93	1046.32	348.77
4.20	50	164.15	1011.24	337.08
4.40	57	187.36	1147.15	382.38
4.60	62	203.91	1245.07	415.02
4.80	68	223.79	1361.98	453.99
5.00	72	237.00	1440.90	480.30
5.20	84	276.88	1671.82	557.27
5.40	90	296.76	1788.73	596.24

Table 4: Results of CPT 2.

Depth (m)	(kg/cm^2)	Estimated Undrained Strength (KPa)	Ultimate bearing Capacity (KPa)	Allowable bearing Capacity (KPa)
0.00	0	0.00	0.00	0.00
0.02	3	9.88	59.92	19.90
0.40	3	9.76	62.83	20.94
0.60	3	9.64	65.75	21.92
0.80	3	9.52	68.66	22.89
1.00	3	9.40	71.58	23.86
1.20	3	9.28	74.50	24.83
1.40	2	5.83	58.41	19.47
1.60	2	5.71	61.33	20.44
1.80	3	8.92	83.24	27.75
2.00	15	48.80	314.16	104.02
2.20	30	98.68	602.08	200.69
2.40	30	98.56	604.99	201.66
2.60	33	108.44	664.91	221.64
2.80	35	114.99	705.82	235.27
3.00	35	114.87	708.74	236.25
3.20	33	108.08	673.66	224.55
3.40	33	107.96	676.57	225.52
3.60	35	114.51	717.49	239.16
3.80	37	121.05	458.40	252.80
4.00	46	150.93	932.32	310.77
4.20	48	157.48	973.24	324.41
4.40	48	157.36	976.15	325.38
4.60	54	177.24	1093.07	364.36
4.80	58	190.45	1171.98	390.66
5.00	67	220.33	1345.90	448.63
5.20	78	256.88	1557.82	519.27
5.40	86	283.43	1712.73	570.91
5.60	87	286.64	1734.65	578.22
5.80	94	309.85	1870.56	623.52
6.00	105	346.04	2082.48	694.16

Bearing capacity calculations: The Bearing Capacity for the pile foundation is determined using Terzaghi's bearing capacity formulae, as stated below;

$$qd = 5.7c\{1+0.3x\frac{B}{L}\} + \gamma D_f \quad \text{for } \varphi = 0$$

Where,

qd = Ultimate bearing capacity

c = Undrained cohesion of the soil

B = Width of footing

L = Length of footing

γ = Unit weight of soil

D_f = Depth of footing

φ = Angle of friction taking as zero for undrained condition of the soil.

RESULTS AND DISCUSSION

Table 1 shows the particle size statistics of the boreholes while Table 2 shows the variations in the index and engineering properties of the sands in the study area.

The lithology in the area consists predominantly of fine sands at the near surface and underlain by fine to medium sands which is extended to the end of the hole. Figs. 2, 3 and 4 show the logs for the three boreholes while Figs. 5 and 6 show the penetrometer log of CPT1 and CPT 2. Tables 3 and 4 show the results of CPT 1 and 2. Figs. 7, 8, and 9 show the particle size distribution curves of BH1, BH 2 and BH 3 at 30.00m, respectively.

The topsoil in BH 1 is characterized by soft, dark grey peat with a thickness of 2.0m. This layer of peat is underlain to 9.0m by medium dense, dark grey fine sand and in turn overlies medium dense to dense, grey fine to medium sand to the terminal depth at 30.0m and becoming light grey at 24.0m.

In Borehole 2, the topsoil is soft, dark grey peat to 0.50m. Immediately underlying the above layer of peat to 1.0m is loose, light brown fine sand with plant roots. From 1.0m to 3.0m is a layer of soft, grey sandy silt which is underlain by medium dense, grey fine sand of 3.0m thickness. From 6.0m to 9.0m is dark grey, fine sand with intercalation of silty clay at 9.0m and from 10.0m to 22.0m is medium dense,

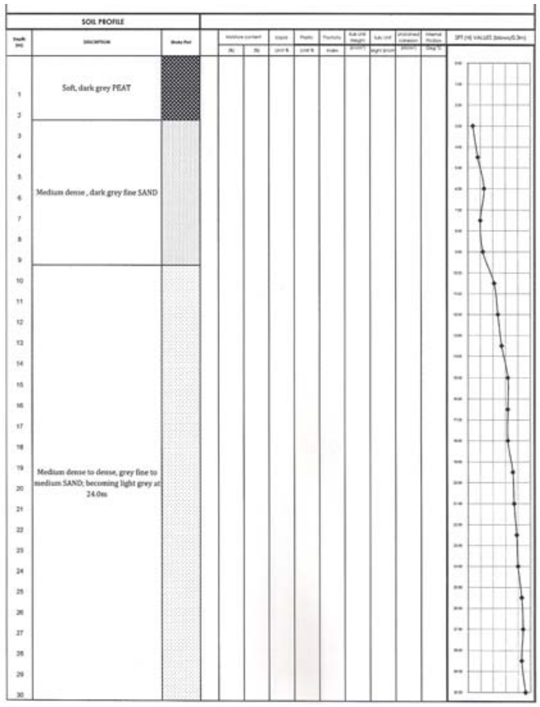

Fig. 2: Log of Borehole 1.

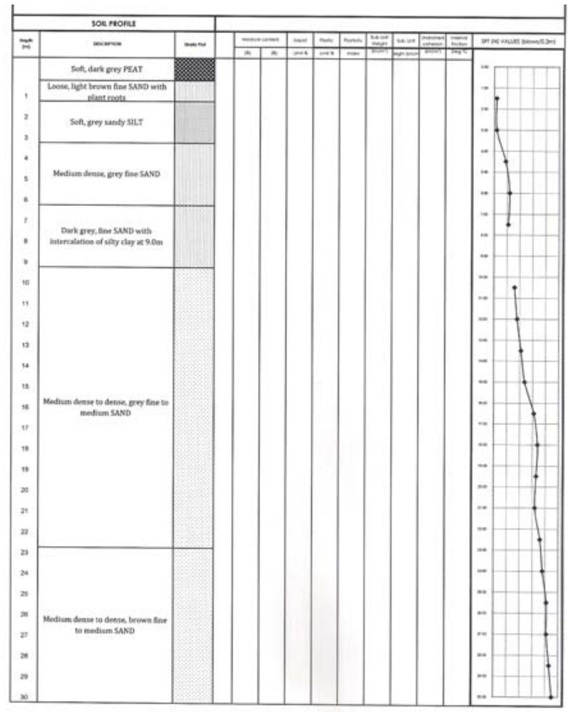

Fig. 3: Log of Borehole 2.

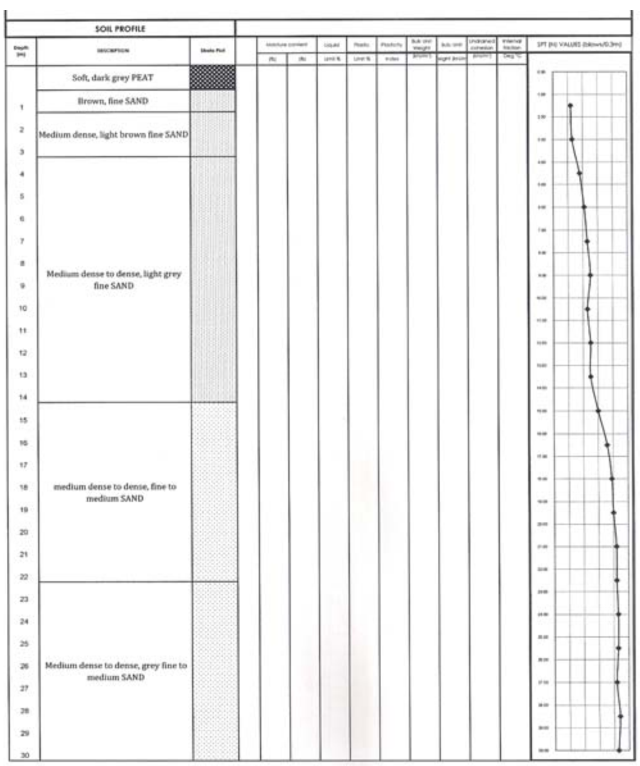

Fig. 4: Log of Borehole 3.

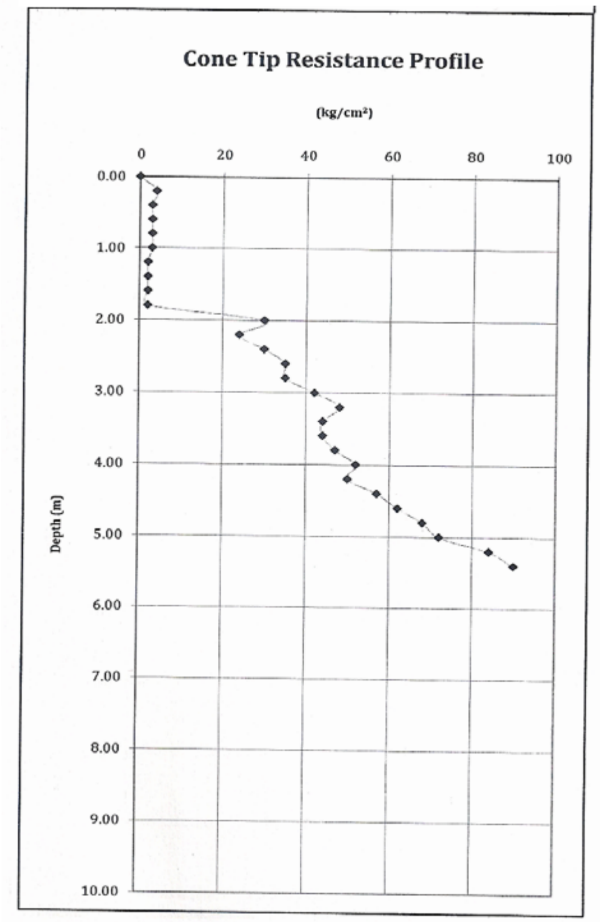

Fig. 5: Penetrometer log of CPT1.

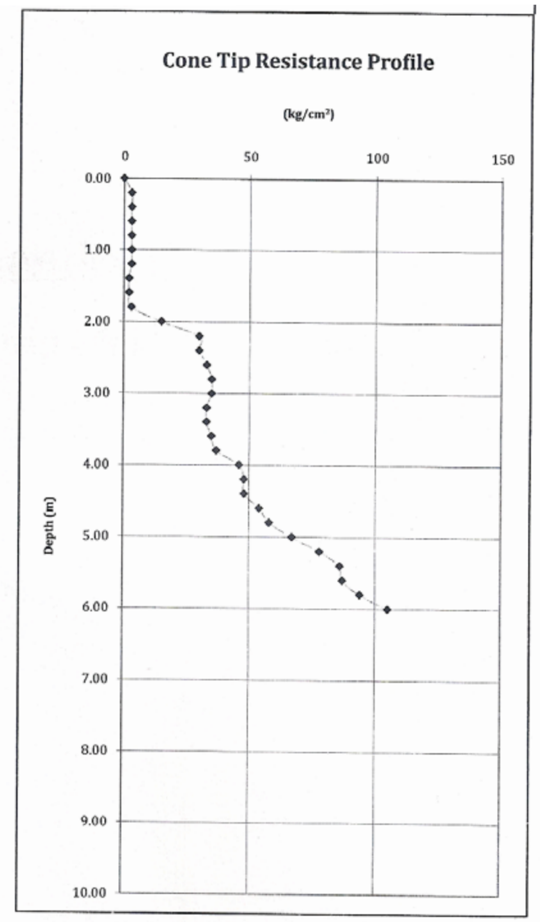

Fig. 6: Penetrometer log of CPT 2.

grey fine to medium sand. From 23.0m to the terminal depth at 30.0m is medium dense to dense, brown fine to medium sand.

The topsoil in Borehole 3 is similar to Borehole 2. However, underlying the peat in BH 3 is brown fine sand to 1.0m and underlying the fine sand to 3.0m is medium dense, light brown fine sand. From 3.0m to 14.0m is medium to dense, light grey fine sand which is in turn underlain by medium dense to dense, fine to medium sand of 8.0m thickness. From 22.0m to the terminal depth at 30.0m is medium dense to dense, grey fine medium sand. Generally, the sand layers in all the boreholes exhibited high SPT values at deeper depths. The area under investigation was flooded during the course of boring operation, an indication that the groundwater condition in the area is high.

CONCLUSIONS

The subsurface soil investigation conducted in this work was carried out in order to determine the litho-stratigraphic sequence at the site, in order to ascertain the engineering properties of the underlying soil and recommend appropriate foundation types for construction in the area. The study reveals that the samples are predominantly fine sands at the near surface and underlain by fine to medium sands which is extended to the end of the hole. Generally, the sand layers in all the boreholes exhibited high SPT values at deeper depths. The results obtained from this study have emphasized the usefulness of geotechnical studies in establishing variation in lithology accompanied by variation in the allowable bearing pressure of foundation soils.

Based on the results of the study, pile foundation is recommended within the sand formation to support heavy facilities and wide strip footing for other smaller facilities and where the load imposed may be excessive, the foundations may be supported by means of continuous footing with foundation beams in order to minimize the problem of differential settlements.

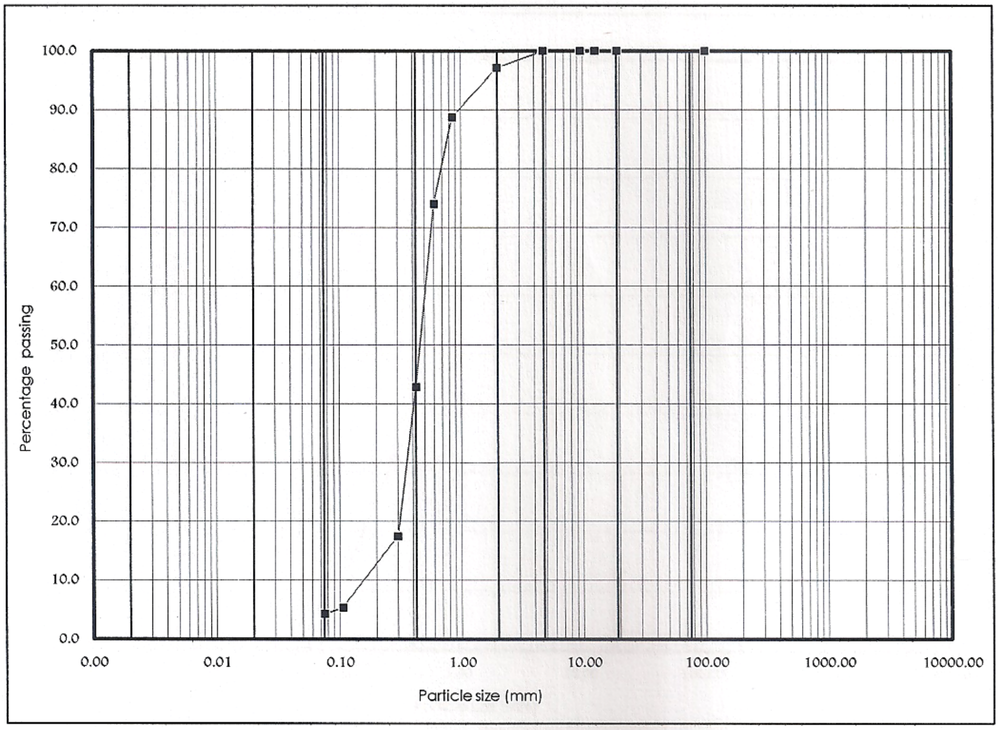

Fig. 7: Particle size distribution curve of BH 1 @ 30.00m.

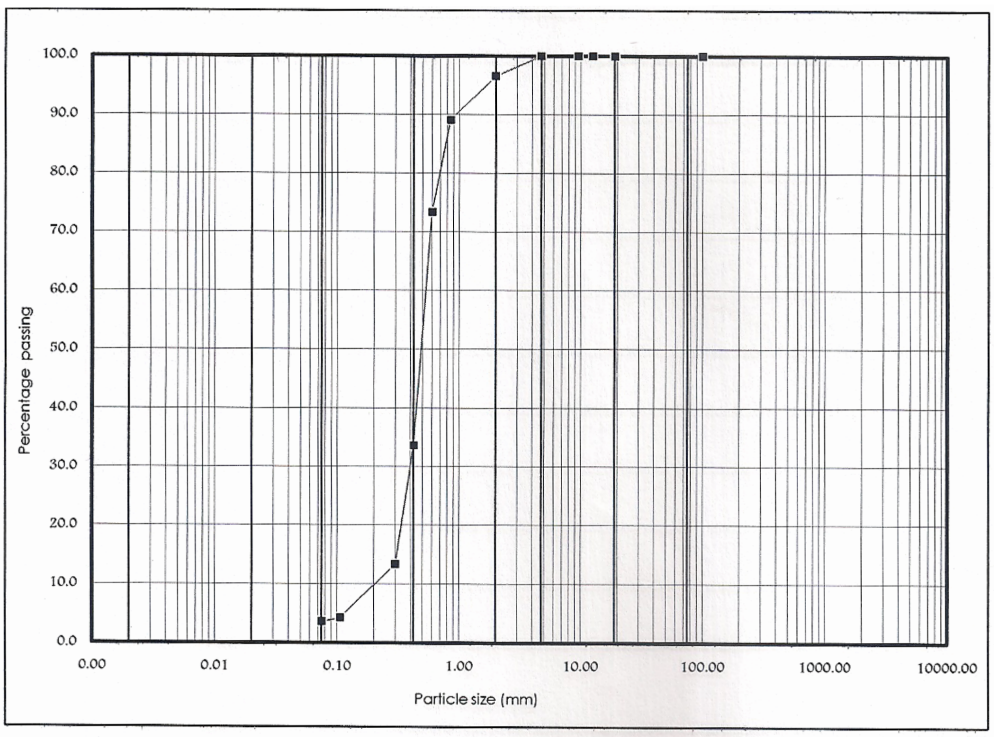

Fig. 8: Particle size distribution curve of BH 2 @ 30.00m.

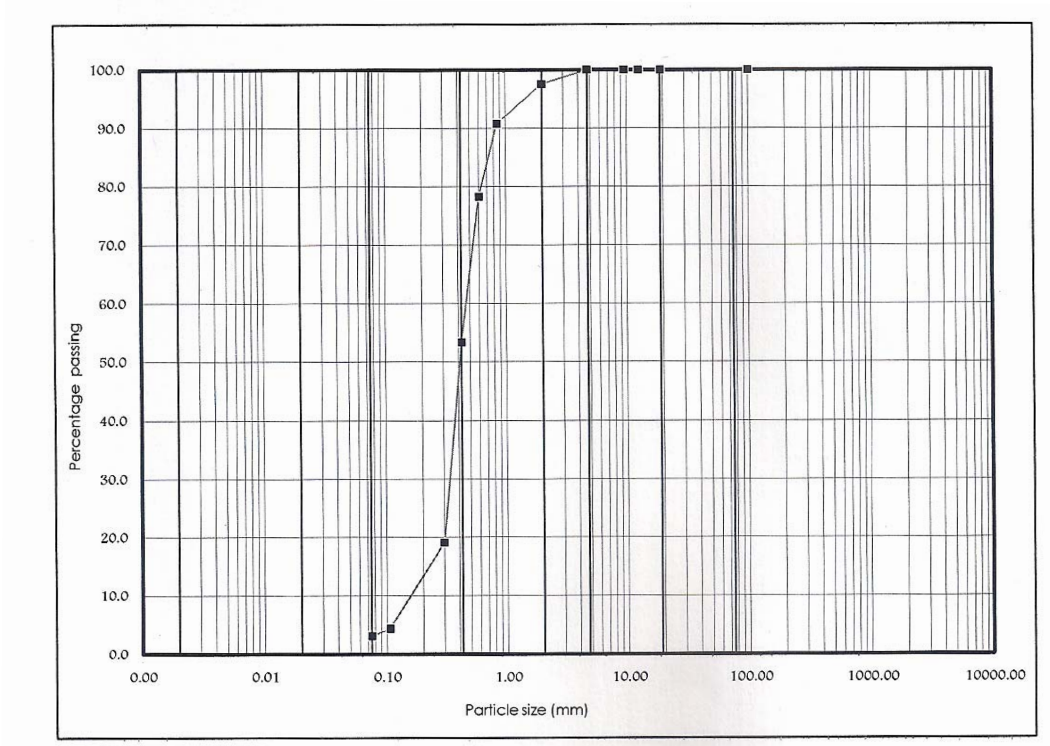

Fig. 9: Particle size distribution curve of BH 3 @ 30.00m.

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